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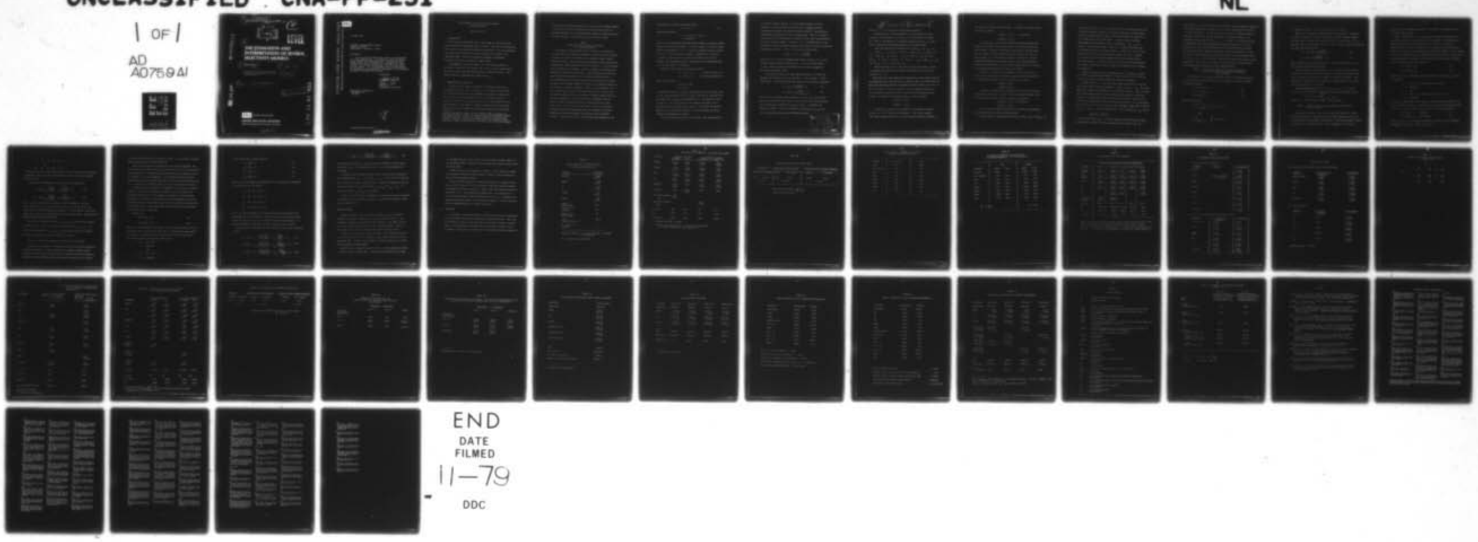

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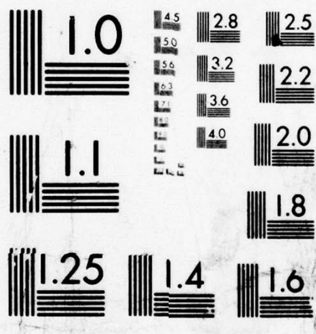
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Robert P. Trost

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The Estimation and Interpretation of Several Selectivity Models

Robert P. Trost*

1. INTRODUCTION

In recent years there have been a large number of studies that deal with the problem of selectivity bias in the data. Here the term "selectivity bias" refers to non-randomly distributed observed data. This non-randomness can occur whenever the data we have are generated by the choices that individuals make. A review of selectivity problems in econometric models can be found in two papers by Maddala (1977).

The purpose of the present paper is to review several models not discussed in Maddala's (1977) papers, and to give a further interpretation of the covariance terms that are particular to selectivity models. This should enhance the understanding of these models.

2. FOUR MODELS OF SELECTIVITY

In this section I present four models of selectivity and discuss the estimation of each. The four models are : (1) measuring the returns of a college education when almost everyone in the sample is working; and when the level of college education does not enter directly into the earnings equations, (2) measuring the returns of a college education when almost everyone in the sample is working; and when the level of college education does enter directly into the earnings equations, (3) measuring

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the returns of a college education, when only part of the sample decides to work, and the level of college does not enter directly into the earnings equations, and, (4) measuring the returns to a specific type of military training. A discussion of these four models follows.

Model 1

A simple model for measuring the returns to a college education

The question this first model tries to answer is: Are expected earnings higher if an individual completes at least one year of college? A naive way to answer this question is to estimate a dummy variable regression equation where earnings are regressed on several explanatory variables and a dummy variable which takes a value of 1 if the individual goes to college and 0 otherwise. There is, however, a self-selectivity problem that needs to be analyzed here. The self-selectivity problem is that some individuals choose to go to college and others do not. If this choosing process is based on potential college versus non-college earnings, then the dummy variable in the above naive approach should not, in general, be treated as exogenous. Rather, if the individuals who go to college are the ones who can most benefit by it, and vice versa for those who choose not to go to college, the dummy variable should be treated as endogenous. The net impact of this endogenous choosing process is that the earnings data we do observe may not be a truly random sample. Here the term "random sample" refers to the sample of college and non-college earnings we would have observed if we could simultaneously measure everybody's earnings both with and without college. In order to correct for this potential non-randomness in the

observed data, I specify the following model.

$$I^* = \gamma^{*\prime} X - \varepsilon^*, \tag{1}$$

where we only observe:

$$I = 1 \text{ iff } I^* \geq 0 \Longleftrightarrow \varepsilon^* \leq \gamma^{*\prime} X$$
$$= 0 \text{ otherwise.}$$

Here I^* is an unobservable underlying index whereby an individual chooses whether or not to go to college, $\varepsilon^* \sim N(o,\sigma^2)$ and γ^* is a vector of parameters to be estimated. If $I^* \geq 0$, then the individual chooses college, and if $I^* < 0$ he does not go to college. Although we do not observe the index I^*, we do observe the choice of whether or not to go to college. This observable choice is represented by the dichotomous index $I = 1$ if $I^* \geq 0$ and $I = 0$ otherwise.

The model also specifies two earning equations:

$$E_1 = \beta_1{}'X_1 + \varepsilon_1 \qquad \text{(college earnings)} \tag{2}$$

$$E_2 = \beta_2{}'X_2 + \varepsilon_2, \qquad \text{(w/o college earnings),} \tag{3}$$

where we only observe;

$$E_1 \text{ iff } I=1, \text{ and}$$

$$E_2 \text{ iff } I=0.$$

In equations (2) and (3), β_1 and β_2 are parameters to be estimated, and ε_1 and ε_2 are distributed $N(0,\sigma_1^2)$, $N(0,\sigma_2^2)$, respectively. The model does not assume that ε_1 and ε_2 are independent of ε^*. The question we want to answer is: for a given level of the exogenous variables, is the expected value of E_1 greater than, equal to, or less than the expected value of E_2? To answer this question we need to estimate β_1 and β_2. Consider the estimation of β_1 first.

If we could observe earnings E_1 for everyone, then there would be

no serious estimation problem. We could simply estimate β_1 by OLS. Similarly, if the E_1 earnings we do observe are randomly selected from the entire sample, then again OLS would be alright. The problem is, the observed E_1 earnings may not be a random sample. That is, the expectation of E_1 for the sub-sample we do observe may not equal the expectation of E_1 for the entire sample. In fact, if ε_1 is correlated with ε^*, the observed E_1 will not be random because we only observe E_1 (and the associated disturbance ε_1) when $\varepsilon^* \leq \gamma^{*\prime}X$. It can easily be shown that:

$$E(\varepsilon_1 \mid \varepsilon^* \leq \gamma^{*\prime}X) = \sigma_{1\varepsilon} \frac{-f(\gamma' X)}{F(\gamma' X)},$$

where $\gamma = \gamma^*/\sigma$, $f(\cdot)$ is the standard normal density function, $F(\cdot)$ is the standard normal cumulative function, and $\sigma_{1\varepsilon}$ is the covariance between ε_1 and ε. Proofs of these two expectations can be found in papers by Lee (1976) and Heckman (1976).

To estimate β_1 and β_2 by a least squares procedure, Lee (1976) and Heckman (1976) suggest a two stage procedure. First, estimate γ with a probit model. Second, estimate by least squares the following two equations:

$$E_1 = \beta_1' X_1 - \sigma_{1\varepsilon} \frac{f(\hat{\gamma}' X)}{F(\hat{\gamma}' X)} + \eta_1 \tag{2a}$$

$$E_2 = \beta_2 X_2 + \sigma_{2\varepsilon} \frac{f(\hat{\gamma}' X)}{1 - F(\hat{\gamma}' X)} + \eta_2 \tag{3a}$$

where $\hat{\gamma}$ is the consistent probit estimate of γ, and η_1 and η_2 are disturbances with zero mean. Least square on (2a) and (3a) will yield consistent, albeit inefficient, estimates of $\beta_1, \beta_2, \sigma_{1\varepsilon}$ and $\sigma_{2\varepsilon}$. Consistent and efficient estimates of all the parameters ($\beta_1, \beta_2\ \sigma_{1\varepsilon}, \sigma_{2\varepsilon}, \sigma_1^2$, and σ_2^2), can be obtained by maximizing the likelihood function:

$$L = \prod_{\substack{\text{all}\\ \text{obs.}}} \left[\int_{-\infty}^{\gamma'X} g(E_1 - \beta_1' X_1, \varepsilon) d\varepsilon \right]^{I} \cdot \left[\int_{\gamma'X}^{\infty} g(E_2 - \beta_2' X, \varepsilon) \, d\varepsilon \right]^{1-I} ,$$

where $g(\cdot\ ,\ \cdot)$ is the bivariate normal density function.

Before going on to the second model, it will be useful to look closer at the covariances, $\sigma_{1\varepsilon}$ and $\sigma_{2\varepsilon}$. More specifically, we should ask: What is the meaning of a negative (or positive) $\sigma_{1\varepsilon}$ or $\sigma_{2\varepsilon}$, and what is a meaningful relationship between the two covariances?

There are eight possible outcomes for $\sigma_{1\varepsilon}$ and $\sigma_{2\varepsilon}$: (1) $\sigma_{1\varepsilon} > 0$, $\sigma_{2\varepsilon} > 0$ and $\sigma_{1\varepsilon} > \sigma_{2\varepsilon}$; (2) $\sigma_{1\varepsilon} > 0$ and $\sigma_{2\varepsilon} > 0$ and $\sigma_{1\varepsilon} < \sigma_{2\varepsilon}$; (3) $\sigma_{1\varepsilon} < 0$, $\sigma_{2\varepsilon} < 0$ and $\sigma_{1\varepsilon} > \sigma_{2\varepsilon}$; (4) $\sigma_{1\varepsilon} < 0$, $\sigma_{2\varepsilon} < 0$ and $\sigma_{1\varepsilon} < \sigma_{2\varepsilon}$; (5) $\sigma_{1\varepsilon} < 0$ and $\sigma_{2\varepsilon} > 0$; (6) $\sigma_{1\varepsilon} > 0$ and $\sigma_{2\varepsilon} < 0$; (7) $\sigma_{1\varepsilon} > 0$, $\sigma_{2\varepsilon} > 0$ and $\sigma_{1\varepsilon} = \sigma_{2\varepsilon}$, and, (8) $\sigma_{1\varepsilon} < 0$, $\sigma_{2\varepsilon} < 0$ and $\sigma_{1\varepsilon} = \sigma_{2\varepsilon}$.

Before deciding if any of these eight outcomes make sense, we need to understand what positive and negative covariances imply in terms of equations (1) - (3).

Recall that the choice equation was written with a minus sign in front of the disturbance term. Because of this, a positive sign for the covariance $\sigma_{1\varepsilon}$ means that individuals who are not expected to choose college (i.e., $\gamma'X < 0$) but do (because $\varepsilon < 0$), have on average lower than expected earnings in the college wage equation (because ε_1 will tend to be negative for this group). In terms of the conditional means, a positive $\sigma_{1\varepsilon}$ means:

$$E(E_1 | I=1) < B_1'X_1$$

$$E(E_1 | I=0) > B_1'X_1.$$

A positive $\sigma_{2\varepsilon}$ means that individuals who are expected to choose college (i.e., $\gamma'X > 0$) but do not (because $\varepsilon > 0$), have on average higher than expected earnings in the non-college wage equation (because ε_2

will tend to be positive for this group). In terms of conditional means, a positive $\sigma_{2\varepsilon}$ means:

$$E(E_2 | I=0) > B_2'X_2 \quad \text{, and therefore}$$

$$E(E_2 | I=1) < B_2'X_2 \ .$$

So a positive $\sigma_{1\varepsilon}$ means that if both the non-college and college groups go to college, the non-college group would earn more than the college group. Similarly, a positive $\sigma_{2\varepsilon}$ means that if neither group goes to college, the non-college group would again earn more than the college group. So in the the case of positive covariances, the non-college group dominates the college groups in both earning equations. Before we decide whether or not these relationships make sense, consider the following interpretation for negative covariances.

A negative $\sigma_{1\varepsilon}$ means that individuals who are not expected to choose college but do, have on average higher than expected earnings in the college wage equation. That is, a negative $\sigma_{1\varepsilon}$ implies:

$$E(E_1 | I=1) > B_1'X_1$$

$$E(E_1 | I=0) < B_1'X_1 \ .$$

A negative $\sigma_{2\varepsilon}$ means that individuals who are expected to choose college but do not, have on average lower than expected earnings in the non-college wage equation. That is, a negative $\sigma_{2\varepsilon}$ implies:

$$E(E_2 | I=0) < B_2'X_2 \quad \text{, and therefore}$$

$$E(E_2 | I=1) > B_2'X_2.$$

So in the case of negative covariances, the college group dominates the non-college group in both earnings equations.

At first glance, it might appear that only outcome 5 ($\sigma_{1\varepsilon} < 0$ and $\sigma_{2\varepsilon} > 0$)

makes intuitive sense. That is, one might expect the college group to have a higher college wage (relative to the non-college group's college wage); and the non-college group to have a higher non-college wage (relative to the college group's non-college wage). I suppose another reasonable guess might be that outcomes 3 and 4 - where both $\sigma_{1\varepsilon}$ and $\sigma_{2\varepsilon}$ are negative - make intuitive sense. That is, the college groups dominates the non-college group in both wage equations. Perhaps the least appealing outcomes that initially come to mind are outcomes 1,2 and 6. Outcomes 1 and 2 say that the non-college groups dominates the college group in both wage equations. Outcome 6 says that the non-college groups dominates the college wage equation and the college group dominates the non-college wage equation.

However, initial guesses are sometimes wrong. In actuality, outcomes 2, 4 and 5 are plausible and outcomes 1, 3 and 6 are not. To see this, one only needs to look at Ricardo's theory of comparative advantage.

Consider outcome 2. In this case the college group earns less than the non-college group in both wage equations. However, since $\sigma_{1\varepsilon} < \sigma_{2\varepsilon}$, the college group has a comparative advantage in the college wage equation. That is, while the college group has lower then mean earnings ($B_1'X$ and $B_2'X_2$) in both wage equations, the difference between mean and actual earnings is smaller in the college wage equation than in the non-college wage equation. So if individuals base the college decision on potential earnings and $B_1'X_1 = B_2'X_2'$, then on average $B_1'X_1' + \varepsilon_1 > B_2'X_2 + \varepsilon_2$ for the college group. This is becasue $\sigma_{1\varepsilon} < \sigma_{2\varepsilon}$ implies

$$E(E_1|I=1) > E(E_2|I=1),$$

in the case where $B_1X_1 = B_2X_2$. A similar argument can be made if $B_1X_1 \neq B_2X_2$. In other words, a model that says individuals choose college if $E_1 > E_2$

implies that $\sigma_{1\varepsilon} < \sigma_{2\varepsilon}$ is the most sensible outcome. Similar arguments concerning the logical consistency of outcomes 4 and 5, and the inconsistency of outcomes 1, 3 and 6 can be made. So long as the only criterion for choosing college is relative earnings in the two wage equations, the necessary condition for consistency of the model is that $\sigma_{1\varepsilon} < \sigma_{2\varepsilon}$. Of course, if the individual looks at intangibles other than earnings when deciding or whether or not to go to college, any of the 6 outcomes mentioned could be consistent with the model. But even under the most general specification of the choice equation, so long as relative earnings enters into the choice equation, the most plausible result is that $\sigma_{1\varepsilon} < \sigma_{2\varepsilon}$. Finally, outcomes 7 and 8 neither refute nor support a priori expectations. Since they are in essence "neutral outcomes," nothing needs to be said about their consistency with the underlying model.

Model 2: A Selectivity Model of Education and Earnings When the Amount of College Enters Simultaneously Into the Model

In this model, let S* denote the "desired" years of college education and S the actual years of college education. E_1 and E_2 are as defined in model 1. The model now becomes:

$$S = S^* = \gamma^{*\prime}X - \varepsilon^* \quad (1)$$

$$E_1 = \alpha S + B_1'X_1 + \varepsilon_1 \quad (2)$$

$$E_2 = B_2'X_2 + \varepsilon_2, \quad (3)$$

where we only observe:

$$\left.\begin{aligned} S &= S^* = \gamma^{*\prime}X - \varepsilon, \\ E_1 &= \alpha S + B_1'X_1 + \varepsilon_1 \end{aligned}\right\} \quad \text{iff} \quad S^* \geq 0$$

,and,

$$\left.\begin{aligned} S &= 0 \\ E_2 &= B_2'X_2 + \varepsilon_2. \end{aligned}\right\} \quad \text{iff} \quad S^* < 0$$

The assumptions about ε, ε_1 and ε_2 are the same as in model 1.

Model 2 is a simultaneous equations model with selectivity. Estimation of model 2 is discussed in detail in Kenny et.al. (1978), and Lee, Maddala and Trost (1977). Briefly, what we do is estimate γ^* and σ^2 (=var. of ε^*) in equation 1 with a Tobit program and get $\hat{S} = \hat{\gamma}^{*\prime}X$. We then estimate the following two stage regression equations:

$$E_1 = \alpha\hat{S} + B_1'X_1 - \sigma_{1\varepsilon}\frac{f(\gamma'X)}{F(\gamma'X)} + \eta_1 \qquad (2a)$$

$$E_2 = B_2'X_2 + \sigma_{2\varepsilon}\frac{f(\gamma'X)}{1-F(\gamma'X)} + \eta_2, \qquad (3a)$$

where $\hat{\gamma} = \hat{\gamma}^*/\hat{\sigma}$ and η_1 and η_2 have zero means. The covariance terms $\sigma_{1\varepsilon}$ and $\sigma_{2\varepsilon}$ have the same interpretation as before.

The main difference between models 1 and 2 is that the choice equation in model 2 is a Tobit type equation rather than a probit type equation, and years of college enters directly in model 2's college wage equation. Other than these two differences, the estimation and interpretation of $\sigma_{1\varepsilon}$ and $\sigma_{2\varepsilon}$ is the same in model 2 as in model 1.

Maximum likelihood estimates of γ, B_1, B_2, $\sigma_{1\varepsilon}$, $\sigma_{2\varepsilon}$, σ_1^2, σ_2^2 and σ^2 in model 2 can be obtained by maximizing the following likelihood function:

$$L = \prod_{s>0} g(\varepsilon, \varepsilon_1) \prod_{s=0} \int_{-\infty}^{\gamma'X} g(\varepsilon, \varepsilon_2)\,d\varepsilon,$$

where $g(\cdot\,,\cdot)$ is the bivariate normal density function.

Model 3: A Model of Labor Force Participation, Wages and the Returns to College.

The purpose of models 1 and 2 was to measure the effect of a college education on earnings; taking into account possible selectivity bias in the observed college and non-college earnings data. Those models assumed, however, that everyone in the sample worked. If this assumption is not valid, a

different model and estimation technique is necessary. A discussion of this alternative model follows.

Model 3 extends model 1 by incorporating the decision of whether or not to work into the model. By specifying the earnings model in this fashion, it becomes apparent that observed earnings may be subject to two types of self-selectivity. First, the college versus non-college earnings data may be subject to the type of self-selectivity bias discussed in models 1 and 2. Second, since we only observe the wages of individuals who choose to work, the wage data may also be subject to the type of self-selectivity bias discussed in Heckman (1974) and Nelson (1977). Thus, model 3 is:

$$I^*_c = B^{*\prime}_c X_c - \varepsilon^*_c \qquad (1a)$$

$$I_p^* = B_p^{*\prime} X_p - \varepsilon_p^* \qquad (1b)$$

where $f(\varepsilon_c^*, \varepsilon_p^*)$ is distributed bivariate normal with correlation ρ_{pc}, and we only observe:

$$\begin{aligned} I_c &= 1 \quad \text{iff} \quad I_c^* \geq 0 \text{ (Choose college in year t)} \\ &= 0 \quad \text{otherwise} \end{aligned}$$

and

$$\begin{aligned} I_p &= 1 \quad \text{iff} \quad I_p^* \geq 0 \text{ (Choose to work in year t + n)} \\ &= 0 \quad \text{otherwise.} \end{aligned}$$

Here I_c^* is an unobservable index whereby an individual decides whether or not to go to college, and I_p^* is an unobservable index whereby an individual decides whether or not to work. Model 3 also specifies two earnings equations:

$$E_1 = B_1' X_1 + \varepsilon_1 \quad \text{(college)} \qquad (2)$$

$$E_2 = B_2' X_2 + \varepsilon_2, \quad \text{(w/o college)} \qquad (3)$$

where, E_1, E_2, β_1, β_2 are previously defined, ε_1 and ε_2 are not necessarily independent of ε_c^* and ε_p^*, and we only observe:

$$E_1 \quad \text{iff} \quad I_c=1 \quad \text{and} \quad I_p = 1$$

and

$$E_2 \quad \text{iff} \quad I_c=0 \quad \text{and} \quad I_p = 1.$$

I could also specify two shadow wage equations, but this point will be discussed elsewhere in a paper by Fishe, Trost and Lurie (1979), and is also discussed in Nelson (1977).

If ε_c^* and ε_p^* are independent, B_1 and B_2 can be estimated from:

$$E_1 = B_1'X_1 - \sigma_{1\varepsilon_p} \frac{f(\hat{B}_p'X_p)}{F(\hat{B}_p'X_p)} - \sigma_{1\varepsilon_c} \frac{f(\hat{B}_c'X_c)}{F(\hat{B}_c'X_c)} + \eta_1 \qquad (2a)$$

$$E_2 = B_2'X_2 - \sigma_{2\varepsilon_p} \frac{f(\hat{B}_p'X_p)}{F(\hat{B}_p'X_p)} + \sigma_{2\varepsilon_c} \frac{f(B_c'X_c)}{1-F(B_c'X_c)} + \eta_2, \qquad (3a)$$

where σ_{ij}'s are covariances, $\hat{B}_p$ and $\hat{B}_c$ are probit estimates of (1a) and (1b), respectively, and η_1 and η_2 have zero means. If ε_c^* and ε_p^* are not independent the estimation approach is similiar , but (2a) and (2b) are messier, and B_p and B_c have to be estimated with a bivariate probit model. Details will be given in Fishe, Trost and Lurie (1979).

The expected relationship between $\sigma_{1\varepsilon_c}$ and $\sigma_{2\varepsilon_c}$ has already been discussed in models 1 and 2. That is, the model only makes sense if $\sigma_{2\varepsilon_c} > \sigma_{1\varepsilon_c}$. The expected relationships for $\sigma_{1\varepsilon_p}$ and $\sigma_{2\varepsilon_p}$ can only be discussed in the context of shadow wage equations, which are not present in model 3.

Model 4: The Effect of Military Training on Civilian Earnings

The purpose of this model is to measure the returns to military occupational training in electronics. A naive procedure is to estimate a dummy variable regression equation where civilian earnings are regressed on several explanatory variables and a set of dummy variables that depend on whether or not a veteran

receives military training in electronics, and/or, a veteran takes a civilian job in electronics after leaving the service.

There are two selectivity problems that flaw the naive approach. The first selectivity problem is that some veterans choose to work in related jobs while others do not. Although the usual procedure treats occupational choice as exogenous, it is really endogenous. The observed earnings differences between those who choose related jobs and those who choose unrelated jobs will not, in general, give unbiased estimates of the earnings effect of training.

A second selectivity problem also complicates the analysis of veterans' earnings. This is the occupational assignment process that occurs upon entering military service. New entrants are assigned to various military occupations on the basis of observable educational background and upon their preferences and other unobservable factors such as occupations available when they entered service. This occupational selection process may also distort post-service earnings comparisons.

The model is:

$$YM^* = B^{*\prime}_m X_m - \varepsilon^*_m \tag{1a}$$

$$YC^* = B^{*\prime}_c X_c + \alpha YM - \varepsilon^*_c \tag{1b}$$

Here YC^* is an unobservable index whereby a veteran chooses whether to work in electronics after leaving the military, YM^* is an unobservable index whereby an individual is chosen for military electronics training, ε^*_m and ε^*_c are distributed bivariate normal, and we only observe:

$$\begin{aligned} YM &= 1 \quad \text{iff} \quad YM^* \geq 0 \\ &= 0 \quad \text{otherwise} \end{aligned}$$

and

$$\begin{aligned} YC &= 1 \quad \text{iff} \quad YC^* \geq 0 \\ &= 0 \quad \text{otherwise}. \end{aligned}$$

I also specify four earnings equations:

$$Y_1 = \beta_1' X_1 + \varepsilon_1 \tag{2}$$

$$Y_2 = \beta_2' X_2 + \varepsilon_2 \tag{3}$$

$$Y_3 = \beta_3' X_3 + \varepsilon_3 \tag{4}$$

$$Y_4 = \beta_4' X_4 + \varepsilon_4, \tag{5}$$

where ε_1 to ε_4 are normally distributed and are not necessarily independent of ε_m^* and ε_c^*; and we only observe

Y_1 iff $YM = 1;\ YC = 1$

Y_2 iff $YM = 0;\ YC = 1$

Y_3 iff $YM = 1;\ YC = 0$

Y_4 iff $YM = 0;\ YC = 0.$

Here Y_1 is civilian earnings if the veteran receives military training in electronics (YM = 1) and chooses to take a civilian job in electronics after leaving the service. Y_2 to Y_4 are civilian earnings defined similarly. A complete explanation of the model is given in Trost and Warner (1978).

If ε_m^* and ε_c^* are independent, we can estimate B_1 to B_4 and the covariances σ_{ij} from:

$$Y_1 = B_1' X_1 - \sigma_{1\varepsilon_c} \frac{f(\hat{B}_c' X_c + \hat{\alpha} YM)}{F(\hat{B}_c' X_c + \hat{\alpha} YM)} - \sigma_{1\varepsilon_m} \frac{f(\hat{B}_m' X_m)}{F(\hat{B}_m' X_m)} + \eta_1 \tag{2a}$$

$$Y_2 = B_2' X_2 - \sigma_{2\varepsilon_c} \frac{f(\hat{B}_c' X_c + \hat{\alpha} YM)}{F(\hat{B}_c' X_c + \hat{\alpha} YM)} + \sigma_{2\varepsilon_m} \frac{f(\hat{B}_m' X_m)}{1-F(\hat{B}_m' X_m)} + \eta_2 \tag{3a}$$

$$Y_3 = B_3' X_3 + \sigma_{3\varepsilon_c} \frac{f(\hat{B}_c' X_c + \hat{\alpha} YM)}{1-F(\hat{B}_c' X_c + \hat{\alpha} YM)} - \sigma_{3\varepsilon_m} \frac{f(\hat{B}_m' X_m)}{F(\hat{B}_m' X_m)} + \eta_3 \tag{4a}$$

$$Y_4 = B_4'X_4 + \sigma_{4\varepsilon_c}\frac{f(\hat{B}_c'X_c+\hat{\alpha}YM)}{1-F(\hat{B}_c'X_c+\hat{\alpha}YM)} + \sigma_{4\varepsilon_m}\frac{f(\hat{B}_m'X_m)}{1-F(\hat{B}_m'X_m)} + \eta_4. \qquad (5a)$$

In equations 2a to 5a, $\hat{B}_c$, $\hat{\alpha}$ and $\hat{B}_m$ are probit estimates of the two choice equations, the σ_{ij}'s are covariances, and η_1 to η_4 are disturbances with zero means.

If veterans look at relative earnings when choosing civilian employment, then we should expect $\sigma_{3\varepsilon_c} > \sigma_{1\varepsilon_c}$ and $\sigma_{4\varepsilon_c} > \sigma_{2\varepsilon_c}$. Also, if the military only gives electronics training to men who have "a comparative advantage in gaining from the training," then we would expect $\sigma_{2\varepsilon_m} > \sigma_{1\varepsilon_m}$ and $\sigma_{4\varepsilon_m} > \sigma_{3\varepsilon_m}$. We might also expect $\sigma_{1\varepsilon_m}$ to $\sigma_{4\varepsilon_m}$ to be negative.

Finally, if ε_m^* and ε_c^* are not independent, the model can still be estimated but equations 2a to 5a are more complicated. Details will be given in Fishe, Trost and Lurie (1979).

3. EMPIRICAL RESULTS

Estimates of models 1 to 4 are given in Tables 1a to 4g, and Table 5 defines the variables. Tables 1a to 1c contain estimates of Model 1. The estimates are based on the Parnes data for young men. Since almost all the men in the sample have jobs, model 1 is the appropriate model. Details of the estimates are given in a paper by Fishe, Trost and Lurie (1979).

Tables 2a to 2d contain estimates of Model 2. The estimates are based on the project talent data for young men. Again, almost all the men in the sample had jobs. Details of the estimates are given in Kenny, et.al. (1979) and Lee, Maddala and Trost (1977).

Tables 3a to 3d contain estimates of Model 3. These estimates are based on the Parnes data for young women. Since only about one-half of the women

in the sample had jobs in the year we used to estimate the model, Model 3 is the appropriate model. Details of these estimates will apnear in Fishe, Trost and Lurie (1979).

Tables 4a to 4g contain estimates of Model 4. These estimates are based on the earnings records of 11,941 veterans. Details of these estimates are given in Trost and Warner (1978).

While a complete discussion of these tables would be too lengthy to give here, it may be useful to see if the estimated covariances have the expected relationships discussed in section 2. Table 6 gives the estimated covariances for models 1 to 4. The expected relationships were: the covariances in col. (2) should be greater than the covariances in col. (1). In general, this expected relationship holds. So the estimates of Models 1 to 4 are consistent with the proposed hypotheses presented in section 2.

4. CONCLUSION

In this paper I review four models of selectivity and give an interpretation of the covariance terms that are particular to selectivity models. While some of the models I examine in this paper have been discussed elsewhere, the hypothesis I present about the expected relationship between covariance is new. In general, I found that the estimates of the four models support my hypothesis.

TABLE 1A

Probit Estimates of College Decision*
for Young Men (Parnes Data)

Variable	Estimates
Constant	-6.4881 (20.52)
DBLACK	.3768 (3.42)
IQ	.0478 (17.38)
DSOUTH	.16 (2.22)
EDFEM	.136 (10.41)
Number of Observations	1863
Number of 1's (college)	906
Number of 0's (w/o college)	957
-2*Log (likelihood ratio)	605.65
DF (Degrees of Freedom)	4

*Dependent Variable = 1 if individual goes to college
= 0 if otherwise

**t - values are in parentheses

TABLE 1B

Two Stage and OLS Results* : Young Men (Parnes Data)

Variables	College** Estimates Two Stage	College** Estimates OLS	w/o College** Estimates Two Stage	w/o College** Estimates OLS
DSOUTH	-.0028	-.0005	-.1923	-.1885
	(.09)	(.01)	(7.05)	(6.89)
DBLACK	-.0854	-.0842	-.1098	-.0826
	(1.56)	(1.54)	(2.89)	(2.24)
AGE	.0619	.062	.0286	.0273
	(11.98)	(12.00)	(6.82)	(6.53)
IQ	.002	.0028	-.0002	.0044
	(.89)	(2.40)	(.01)	(4.33)
DMARRIED	.1946	.1941	.1379	.1387
	(6.08)		(4.73)	(4.74)
Constant	-.3267	-.43495	.6014	.3056
		(6.07)		
Truncation Variable $\frac{-f}{F}$	.0297			
	(.42)			
Truncation Variable $\frac{f}{1-F}$			.1868	
			(2.83)	
# of Obs.	904	904	957	957
$\bar{R}^2$	.2229	.2236	.1793	.1732
Std Error	.43174	.43154	.38252	.38393

* Dependent Variable= Ln (wage)

** t-Values are in parentheses. For the two stage estimates the t-values overstate the true asymptotic t's.

Table 1C

Mean Wages for Young Men (Parnes Data)

Raw Data		Predicted* from OLS Estimates		Predicted* from two Stage Estimates	
college	w/o college	college	w/o college	college	w/o college
$5.55	$4.58	$4.29	$4.29	$4.40	$3.76
Δ = $.97		Δ = $0.0		Δ = $.64	

*predictions are based on Age =26,
IQ = 100,
North, white and single.

Table

PROBIT EQUATION TO EXPLAIN THE DECISION OF
WHETHER OR NOT TO GO TO COLLEGE

Variable	Coeff. Est.	S.E.
Const.	-5.259	2.108
Rural (Dummy)	- .164	.093
Split	- .078	.145
MATH	.015	.001
MOCWAG	.922	.589
EDMAL	.044	.017
EDFEM	.029	.019
CHIL	- .057	.021

PROBIT EQUATION TO EXPLAIN THE DECISION OF
WHETHER OR NOT TO GO TO COLLEGE

Table 7b

OLS AND TOBIT EQUATIONS EXPLAINING YEARS OF COLLEGE EDUCATION S. (S = 0 for 464 obs.)

Variable	OLS Coeff.	OLS S.E.	Tobit Coeff.	Tobit S.E.
Constant	-8.091		-12.805	3.169
Rural (Dummy)	- .100	.136	- .270	.203
Split	- .297	.213	- .415	.321
MATH	.0290	.0014	.0415	.0022
MOCWAG	1.675	.629	2.2538	.8881
EDMAL	.0627	.0230	.0923	.0333
EDFEM	.0879	.0264	.1153	.0384
CHIL	- .1264	.0307	- .1916	.0456
	$\bar{R}^2$ = .3620, SE = 2.0206		σ_1 = 2.7645	

Table 2c

OLS ESTIMATES OF EARNINGS EQUATIONS

	Coefficients and (in parentheses) standard errors				
Variable	Eq. 3.1	Eq. 3.2	Eq. 3.3	Eq. 3.4	Eq. 3.5
Married (Dummy)	.1534 (.0264)	.1537 (.0260)	.1553 (.0261	.2671 (.0481)	.0991 (.0306)
Rural (Dummy)	- .0752 (.0260)	- .0748 (.0257)	- .0717 (.0257)	- .1457 (.0401)	- .0260 (.0333)
MATH	.0019 (.0003)	.0013 (.0003)	- .0012 (.0003)	.0010 (.0005)	.0014 (.0004)
HC	- .0115 (.0052)	- .0084 (.0052)	- .0090 (.0052)	.0089 (.0079)	- .0228 (.0069)
S		.0437 (.0072)	.0321 (.0051)		.0406 (.0074)
College Ed. (Dummy)	.0749 (.0256)	-.0812 (.0361)			
Constant	5.803	5.851	5.833	5.762	5.825
$\bar{R}^2$	.09466	.11769	.11507	.09272	.10411
S.E.	.3925	.3875	.38804	.3927	.3804
# of obs.	1373	1373	1373	464	909

In Eq. 3.1 years of college is omitted. Only college education dummy is used.
In Eq. 3.2 both years of college and college education dummy are used.
In Eq. 3.3 only years of college is used. The college dummy is dropped.
Eq. 3.4 is a separate earnings equation for those with no college education.
Eq. 3.5 is a separate earnings equation for those with college education.

Table 2d

ML Estimates of the Complete Model

I. Years of College Education S

VARIABLES	Tobit ML	ML Estimation
Rural		-0.2731 (0.1869)
Split	same as estimates in table 2b	-0.4095 (0.3038)
MATH		0.0421 (0.0023)
MOCWAGE		2.3930 (0.8572)
EDMAL		0.0914 (0.0305)
EDFEM		0.1146 (0.0369)
CHIL		-0.1912 (0.0449)
Constant		-13.3150 (3.0666)

II. Earnings of Individuals with College Education

VARIABLE	Two Stage Consist. Estimation	ML Estimation
Marital Status	0.1029 (0.0314)	0.1033 (0.0324)
Rural	-0.0272 (0.0349)	-0.0174 (0.0405)
MATH	0.0013 (0.0009)	0.0012 (0.0009)
HC	-0.0280 (0.0070)	-0.0278 (0.0066)
S	0.0466 (0.0333)	0.0378 (0.0177)
Constant	5.8211 (0.1710)	5.8851 (0.0849)

Table 2d (Continued)

III. Earnings of Individuals with NO College Education

VARIABLES	TWO STAGE CONSIST ESTIMATION	ML ESTIMATION
Marital Status	.2719 (.0475)	0.2696 (0.0454)
Rural	-.1088 (.0472)	-0.1096 (0.0454)
MATH	-.0022 (.0014)	-0.0022 (0.0006)
HC	.0097 (.0078)	0.0101 (0.0082)
Constant	5.7483 (.0719)	5.7384 (0.0741)

IV. Error Variances

VARIABLES	CONSISTENT ESTIMATION	ML ESTIMATION
σ_1^2	7.6425	7.3790 (0.4974)
σ_2^2	0.1495	0.1509 (0.00008)
σ_3^2	0.1519	0.2058 (0.0021)
$\sigma_{1\varepsilon}$	-0.00259	0.0022 (0.1375)
$\sigma_{2\varepsilon}$	0.7979	0.7962 (0.0459)

Likelihood value = - 3198.72

Table 3a

Number of Observations for Young Women
(Parnes Data)

		IC			
		1	0		
IW	1	550	620	Σ =	1170
	0	270	759	Σ =	1029
		820	1379		2199

Table 3B: Probit Estimates of College and Work Decision Functions for Young Women (Parnes Data)

Variables	College Decision Estimates* Dep.Var. = 1 if college = 0 w/o college	Labor Force Participation Estimates* Dep. Var. = 1 if work = 0 Not Work
DBLACK	.6243 (6.995)	.2268 (2.70)
Age		-.0322 (3.00)
IQ	.0348 (13.92)	.00989 (4.61)
DMarried		-.4268 (5.93)
DNE	-.2121 (2.17)	-.1748 (1.83)
DNC	-.2427 (2.65)	-.0789 (.89)
DSOUTH	.0066 (.07)	.099 (1.13)
EDFEM	.1848 (14.44)	
DCHIL		-.9883 (16.28)
Constant	-5.9475 (19.93)	.7723 (2.07)
# of Obs.	2199	2199
# of 1's	820	1170
# of O's	1379	1029
-2xlog (Likelihood Ratio)	605.44	483.63
DF(Degrees of Freedom	6	8

* t-values are in parentheses

Table 3C: OLS and Two Stage Regression Results* for Young Women (Parnes Data)

VARIABLES	College Estimates* TWO STAGE	OLS	w/o College Estimates** TWO STAGE	OLS
DBLACK	.1536 (3.29)	.1587 (3.43)	-.0182 (.43)	.0170 (.43)
AGE	.0437 (6.73)	.0355 (5.85)	.0139 (2.56)	.0116 (2.17)
IQ	.0043 (2.26)	.00387 (2.97)	.00158 (.88)	.0049 (4.10)
DMARRIED	.0339 (.87)	-.0414 (1.29)	.0142 (.38)	-.0153 (.48)
DNE	.0614 (1.21)	.0559 (1.11)	.0223 (.43)	.00689 (.13)
DNC	-.00996 (.21)	-.0022 (.04)	-.0476 (.99)	-.0705 (1.50)
DSOUTH	-.0641 (1.41)	-.0478 (1.04)	-.1529 (3.28)	-.1561 (3.341)
$\frac{-f(\hat{B}'_C X_C)}{F(\hat{B}'_C X_C)}$	-.0730 (1.33)			
$\frac{f(\hat{B}'_C X_C)}{1-F(\hat{B}'_C X_C)}$			.1406 (2.10)	
$\frac{-f(\hat{B}'_W X_W)}{F(\hat{B}'_W X_W)}$	.2143 (3.31)		.0831 (1.58)	
CONSTANT	4.3449	4.581	5.2488	5.0127
# of Obs.	550	550	620	620
Std. Error	.3592	.36285	.3595	.36102
$\bar{R}^2$	.10345	.08514	.07324	.0655

*Dependent Variable = Ln (wage x 100)

** t-values are in parentheses. For the two stage estimates the t-values overstate their true asympototic t's.

Table 3D: Mean Wages for Young Women (Parnes Data)

Raw Data		Predicted from OLS Estimates*		Predicted from two Stage Estimates*	
College	w/o College	College	w/o College	College	w/o College
\$3.97	\$3.24	\$3.62	\$3.32	\$3.69	\$3.20
Δ = \$.73		Δ = \$.30		Δ = \$.49	

* Predictions are based on Age = 26, IQ = 100, Single, West and White.

TABLE 4a

NUMBER OF OBSERVATIONS, BY
TYPE OF MILITARY TRAINING AND CIVILIAN
OCCUPATION

Civilian Occupation	Military Training YM = 1	YM = 0	Total
YC = 1	806	867	1673
YC = 0	4124	6144	10,268
Total	4930	7011	11,941

TABLE 4b

AVERAGE YEARLY EARNINGS AND STANDARD DEVIATION OF EARNINGS 1970-74, BY TYPE OF MILITARY TRAINING AND CIVILIAN OCCUPATION*

	Military Training		
Civilian Occupation	YM = 1	YM = 0	Marginal
YC = 1	9400 (2919)	8958 (2925)	9171 (2930)
YC = 0	8352 (2933)	8775 (3411)	8605 (3234)
Marginal	8524 (2956)	8798 (3355)	

*Standard deviations in parentheses.

TABLE 4c

OLS EARNINGS REGRESSION WITH DUMMY VARIABLES*

Variable	Coefficients
Intercept	1106.64
AFQT	13.62 (10.57)
ED	522.11 (25.12)
White	586.43 (4.72)
D1(YM=1;YC=1)	695.19 (6.06)
D2(YM=0;YC=1)	368.47 (3.34)
D3(YM=1;YC=0)	-109.25 (1.76)
RSQ	.10512
Std. Error	3026.90
No. of Observations	11941
Mean of Dependent Variable	8684.77

*T-values in parentheses

TABLE 4d

OLS EARNINGS EQUATIONS*

Variable	YM=1;YC=1	YM=0;YC=1	YM=1;YC=0	YM=0;YC=0
Intercept	2386.76	3404.63	2777.55	184.16
AFQT	21.19 (4.51)	23.17 (5.34)	10.91 (5.28)	13.80 (7.28)
Ed	427.29 (3.93)	297.71 (3.40)	404.73 (10.63)	587.21 (21.56)
White	650.93 (1.01)	793.74 (1.62)	301.37 (1.45)	709.89 (4.17)
RSQ	.06649	.07733	.05612	.12837
Std Error	2822.38	2811.77	2850.62	3185.22
No. of Observations	806	867	4124	6144

*t-value in parentheses

TABLE 4e

PROBIT ANALYSIS ON THE DEPENDENT VARIABLE YM

Variable	Coefficient	t-value
Intercept	-.4617	6.38
Army	-.1343	2.80
Navy	.0852	1.65
Marine Corps	-.6753	7.78
Enlistee	.4306	14.20
Race	.1118	2.09
Ed < 11	.2193	5.50
Ed = 11	-.0269	.45
Ed > 12	-.7323	18.42
AFQT	.0020	3.65

Number of Observations = 11941

Number trained in electronics = 4903

Number not trained in electronics = 7011

-2x Log of Likelihood Ratio (df = 9) = 1034.132

Log of Likelihood function = -7577.5436

TABLE 4f

PROBIT ANALYSIS OF THE DEPENDENT VARIABLE YC

Variable	Coefficient	t-Value
intercept	-1.5487	14.59
E4	.0632	1.14
E5	.1494	2.59
E6	.0544	.37
Army	- .1262	2.12
Navy	- .0259	.43
Marine Corps	- .2273	2.08
Enlistee	- .0432	1.12
Race	.1623	2.20
Ed < 11	.0201	.39
Ed = 11	- .0063	.08
Ed > 12	- .5126	10.18
AFQT	.0065	9.50
YM	.1038	3.43

Number of Observations	= 11941
Number taking Civilian jobs in electronics	= 1673
Number taking non-electronics civilian jobs	= 10268
-2x Log of likelihood ratio (df=13)	= 248.656
Log of likelihood function	= -4713.6279

TABLE 4g

TWO STAGE ESTIMATES OF EARNINGS EQUATIONS*

Variable	YM=1;YC=1	YM=0;YC=1	YM=1;YC=0	YM=0;YC=0
intercept	6871.97	7855.36	1189.68	- 248.14
AFQT	4.79 (.64)	11.04 (1.74)	5.05 (1.50)	5.59 (2.04)
Ed	422.30 (3.63)	377.18 (3.72	367.83 (8.90)	613.80 (16.53)
White	1161.39 (1.75)	1065.85 (2.13)	444.95 (2.05)	889.79 (5.02)
$\frac{-f(\hat{\beta}'_m X_m)}{F(\hat{\beta}'_m X_m)}$	-2028.69 (3.53)		-1243.01 (4.83)	
$\frac{f(\hat{\beta}'_m X_m)}{1-F(\hat{\beta}'_m X_m)}$		- 961.35 (1.54)		-1390.30 (4.96)
$\frac{-f(\hat{\tilde{\beta}}'_c \tilde{X}_c)}{F(\hat{\beta}'_c \tilde{X}_c)}$	3837.35 (3.05)	2689.92 (2.70)		
$\frac{f(\hat{\tilde{\beta}}'_c \tilde{X}_c)}{1-F(\hat{\beta}'_c \tilde{X}_c)}$			3754.57 (3.04)	5251.47 (4.92)
RSQ	.07997	.08294	.06099	.13254
Std Error	2801.92	2803.20	2843.26	3177.61
No. of Observations	806	867	4124	6144

*The t-values in parentheses are slightly biased. See Lee, Maddala and Trost (1977) for a discussion.
Also, $\tilde{B}_C$ contains B_C and α; and $\tilde{X}_C$ contains X_C and YM.

TABLE 5

List of Variables

E	= Natural logarithm of hourly wage
Y	= Annual Earnings
S	= Years of college education in 1971
MATH	= Score on a composite of mathematics achievement tests in 1960
SPLIT	= 0 if children living with both mother and father in 1960 = 1 otherwise
EDMAL	- Years of father's education
EDFEM	= Years of mother's education
RURAL	= 1 if pupils in grades 9 - 12 came from an area primarily small town (under 5,000 people) or rural farm =0 otherwise
MOCWAC	= (mean occupational wage) Log of mean earnings (as of 1960) of full time workers in father's occupation
HC	= Number of jobs held between 1965 and 1970
DBLACK	=1 if non-white =0 otherwise
DSOUTH	=1 if live in South =0 otherwise
DNE	=1 if live in Northeast =0 otherwise
DNC	=1 if live in North Central =0 otherwise
DMARRIED	=1 if married =0 otherwise
DCHIL	=1 if have children $\leq$ 5 years of age =0 otherwise
IQ	= IQ Score
AGE	= Age in years
AFQT	= Armed Forces Qualifying Test (an IQ type test)
White	=1 if white =0 if otherwise
YM	=1 if individual receives military training in electronics =0 otherwise
YC	=1 if individual takes a civilian job in electronics after the military =0 otherwise
IC	=1 if individual goes to college =0 otherwise
IW	=1 if individual works =0 otherwise

Table 6: A Comparison of Estimated Covariances for Models 1 to 4

Model	Col. 1* Estimated covariance between decision equation and earnings equation in regime where I = 1	Col. 2** Estimated covariance between decision equation and earnings equation in regime where I = 0
1. Model 1: compare $\sigma_{1\varepsilon}$ to $\sigma_{2\varepsilon}$	.0297	.1868
2. Model 2: compares $\sigma_{1\varepsilon}$ to $\sigma_{2\varepsilon}$	.0022	.7962
3. Model 3: compares $\sigma_{1\varepsilon}$ to $\sigma_{2\varepsilon}$	-.0730	.1406
4. Model 4: compares $\sigma_{1\varepsilon c}$ to $\sigma_{3\varepsilon c}$	3837.35	3754.57
compares $\sigma_{2\varepsilon c}$ to $\sigma_{4\varepsilon c}$	2689.92	5251.47
compares $\sigma_{1\varepsilon m}$ to $\sigma_{2\varepsilon m}$	-2028.69	-961.35
compares $\sigma_{3\varepsilon m}$ to $\sigma_{4\varepsilon m}$	-1243.01	-1390.30

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* $\sigma_{1\varepsilon}$, $\sigma_{1\varepsilon c}$, $\sigma_{2\varepsilon c}$, $\sigma_{1\varepsilon m}$, $\sigma_{3\varepsilon m}$

** $\sigma_{2\varepsilon}$, $\sigma_{3\varepsilon c}$, $\sigma_{4\varepsilon c}$, $\sigma_{2\varepsilon m}$, $\sigma_{4\varepsilon m}$.

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